VOLUME 79 SEPARATE No. 308

# PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

OCTOBER, 1953

# MOVEMENTS IN THE STRUCTURAL CONCRETE AT CONOWINGO HYDRO PLANT

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Presented at
New York City Convention
October 19-22, 1953

POWER DIVISION

*(Discussion open until February 1, 1954)*



**Headquarters of the Society**
**33 W. 39th St.**
**New York 18, N. Y.**

PRICE $0.50 PER COPY

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

# MOVEMENTS IN THE STRUCTURAL CONCRETE AT CONOWINGO HYDRO PLANT

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Philadelphia Electric Company's Conowingo Hydro Plant is located on the Susquehanna River about four miles above tide water, where U. S. Highway #1 crosses the river on the dam. The Susquehanna River runs approximately north to south with the power house on the west bank.

The dam is all concrete masonry construction designed as a gravity section. Its total length of 4,648 feet includes the power house headworks which is 950 feet long and 2,385 feet of ogee type gate controlled spillway section.

This paper is concerned with the structural movements of the concrete in the power house only. No noticeable movements have been observed in the dam.

The power house substructure was carried to a maximum depth at Elevation -20.5 feet at the hydracone draft tubes of four of the wheels. On the other three wheels, a spreading type of draft tube was used which required excavation to Elevation -16.5 feet. All elevations are referred to U.S.C. & G. datum.

The main power house superstructure of the initial installation includes the generator room, which is about 70 feet wide by 75 feet high by 620 feet long. Between the generator room and the headworks is a two story section about 50' wide containing the 13,800 volt bus and the switching equipment, above which are located the main transformers. The 220 kv switching station is located on the roof of the generator room. The operating floor of the plant is at Elevation +46; the generator floor, Elevation +60 and the high point of the roof, Elevation +121.60.

The initial and present installation of this plant consists of seven 54,000 hp water wheels driving 36,000 kw generators. The wheels operate at 81.8 rpm under a head of 89 feet. Provision for four additional units was made in the initial installation.

A structural steel pit liner and generator support imbedded in concrete is provided for each main unit. It is attached to the speed ring of the water wheel and designed to carry the weight of the generator and thrust bearing load down to the upper portion of the speed ring, whence the load is transferred through the guide vanes to the lower ring and into the power house substructure. The entrances to the plate steel riveted scroll cases are controlled by 27 foot diameter butterfly valves on vertical shafts.

The frame of the power house superstructure is designed of reinforced concrete on structural steel. The concrete roof of the generator room is carried on steel trusses. All loads imposed by the switching station on the roof are carried down to the substructure through steel columns heavily reinforced with concrete. The loads of the two 150 ton cranes in the generator room are carried on separate steel columns which are tied to the building columns for lateral support only. The power house structure contains 236,000 cubic yards of concrete and 4,600 tons of structural steel.

Construction of this plant was started in March 1926. The first concrete was poured in August of that year. The final concrete was poured on December 31, 1927. The first unit went into operation March 1, 1928 and the complete plant was in commercial operation June 1, 1928.

### Initial Evidence of Movement

By 1940, pronounced structural movements in the power house came to attention. The original installation included in the power house structure several reference points. One of these was on the down river wall opposite Unit # 4. It consisted of a bracket on the parapet above the generator room roof about Elevation 125 feet with a brass plug at the roof level and one just above the stop-log gallery at Elevation 46. Checking both these points with a plumb line gave definite indications of movements throwing the down river wall out of plumb. Two similar sets of plumb points, one at Unit # 1 and one at Unit # 7 were added in 1941 and, subsequently, movements of the same nature at these locations were observed. The out of plumb at Unit #4 by 1943 was one-half inch.

### Binding of Butterfly Valves

At about the same time, trouble was encountered in the operation of the butterfly valves. These valves were encased in the substructure concrete up to a plane about two feet below their horizontal center line, the binding occurred in this area. Operating clearances were maintained for some time by periodic grinding of the bronze seals as long as sufficient metal was available. Meanwhile check points were installed and the fact was established that the lower half of the housing was being squeezed out of round by the surrounding concrete. After careful studies for the most economical way of correcting this condition, it was decided to free the lower half of the casing from the concrete surrounding it. The work is being completed this year on the last two of the seven valves.

Even prior to the concrete removal, there was considerable leakage through the concrete in the valve areas, the more noticeable being at Unit #5 which also had the first binding trouble. This leakage increased as concrete was removed, so that it was necessary to repair eroded areas and pressure grout each of the penstocks. Leakage was reduced considerably and no appreciable binding has been experienced since completion of these operations.

### Concrete

In 1943 investigations were started on the aggregates used in the concrete and the placing methods. In the course of this investigation, the records revealed that in the first 62,000 yards of concrete placed in the substructure of the power house, 60,000 tons of rock from the power house excavation was crushed on the job and used as the course aggregate.

A study of construction pictures and reports also indicated that very high slump concrete was used which was made necessary because of the fact that a chuting system was used for placing concrete throughout the power house area. The areas in which the local stone was used were determined by studies of the progress reports and diamond core borings to obtain cylinders for testing.

The geological reports of the stone in the area involved were also carefully studied and it was determined that in light of present day knowledge the

igneous and metamorphic rocks at the Conowingo site probably contained materials which when used as aggregate in concrete might chemically react with deleterious effects.

The study of the record showed that the crusher plant on the job was shut down after production of 60,000 cubic yards of aggregate due to the fact that excessive quantities of fines were produced in the operation. The washing required to make this stone suitable for use in the concrete proved less economical than the importation of course aggregate.

The areas in which the suspicious material was used were plotted on typical cross sections of the plant and the possible effects studied. It became evident that any change in volume of the concrete prepared with this stone must have a significant effect on the down-river and superstructure portions of the power house.

There are no expansion joints in the substructure but there are two expansion joints in the superstructure (above El. 46), one between Units 1 and 2, and one between Units 5 and 6.

## Tests on Concrete

Concrete cylinders were cored out of the monolith in the inspection tunnel to provide substructure specimens and similar cores from the transformer court wall provided superstructure specimens. The Portland Cement Association was engaged to make tests on these cores, 6'' diameter by 12'' to 32'' long, the length being determined by the breakage of the core during the drilling. They were shipped to the Chicago Research Laboratory of the Association in special containers and there prepared for compression, thermal coefficient, absorption and specific gravity tests; in addition specimens were prepared for Autoclave, Petrographic and X-ray refraction.

Compression tests of the substructure concrete showed a variation of 20% from the average but all tested more than double the design strength of 1600#/sq. in. The lateral modulus of elasticity as determined by the sonic method was approximately 4 1/2 million. The tests for thermal expansion in the dry state were consistent with usual results which in many cases shows a slight decrease in volume. In contrast with this, wet specimens exposed to recurrent changes in temperature varying from 20$^{o}$F to 85$^{o}$F showed a cyclic change with a net increase in length.

Microscopic examination of polished and broken sections of the cores disclosed some evidence of alkali-aggregate reaction in the substructure concrete. The apparent specific gravity of the concrete was found to be 2.2 to 2.4. Absorption values appear to be reasonable for this class of concrete. Autoclaving of prisms (cut from cores) show a low percentage of expansion thus indicating all the cement had been hydrated. Some special laboratory specimens made with a high alkali cement and fragments of the broken cores showed a relatively high expansion. Long range tests for a period of eighteen months or more in the laboratory on two cores stored in air over water at 110$^{o}$F register 0.019% and 0.043% increase in length. Similar tests of laboratory made prisms showed an increase of 0.012% for low alkali cement, 0.046% for high alkali cement and 0.082% for high alkali cement with 1% sodium hydroxide added.

Cores of the substructure concrete which were immersed in water and alternately heated and cooled so that they received a daily cycle of temperature change from 90$^{o}$F to 40$^{o}$F, were tested for length and after 50 cycles showed 0.070% increase at 90$^{o}$F and 0.043% at 40$^{o}$F. Similar tests on cores taken from the head works show 0.057% and 0.026% respectively.

## Survey System

In 1943, it was also decided to install a complete system of check points to measure movements of the structure. Ten east and west lines were established which are respectively identified as follows: The "R" Line is on the stop log gallery at Elevation +46.0 and is the base line for all north and south movements. The three monuments controlling this line are carefully located well back from the banks of the river with two of the monuments on the west bank. All monuments are constructed according to standards of the U. S. Coast and Geodetic Survey and are carried to bed rock. Another line on elevation +46' is designated as the "A" Line and is approximately 16' north of the "R" Line. A third line on elevation +46', designated as the "B" Line, is north of the generators and is approximately on the center line of the butterfly valves. A fourth line at this elevation is at the north wall of the generator room and is noted "BW." Another line is on elevation 80 in the head works wall and is accessible from the transformer transfer court. At elevation +60.0' two lines were established, the "B" Line being immediately over the "B" Line on Elevation +46 and the "A-B" Line is on the wallway around the generator. One series of measurements are referred to the "B" Line at Elevation +60 and are taken on a plug on each arm of the generator supporting frame to determine whether these frames are remaining in a horizontal plane which would also indicate any misalignment of the supporting barrel and the turbine shaft. There are two lines on Elevation +35, one being immediately below the "A" Line at Elevation +46 and another line as far north as possible which is designated as the "A-B" Line, being south of the "B" Line at Elevation +46. Another line is in the inspection tunnel below the intakes at elevation +1. Each of these lines were installed parallel to the "R" Line and have one or two points on each line per main unit. The base line for east and west movements is controlled by two monuments down-river from the plant, well back from the west bank, the northerly one of which is used for the vertical datum. This line projected northward enters the turbine room at Elevation +46 and intersects the "R," the "A" and the "B" Lines at that elevation with plugs at each intersection. Most of the points for this survey system consist of a bronze plug carefully anchored and grouted into the concrete. A very small center punch mark was made in each plug and this became the zero (initial) reading. A few control points are on the steel trusses of the turbine hall roof to determine whether any movement occurs in the north and south direction, but this has proven to be of a negligible quantity during the past ten years. Plumb lines from the "B" Line at Elevation +46 are used for measurements around the butterfly valve housings.

All instruments and methods used in this work conform to specifications of the United States Coast and Geodetic Survey for first order surveying.

## Survey Results

Readings taken on these several lines have shown a rather variable pattern but the net result has been southward movement with the magnitude increasing from the headworks to down-river extremities of the plant. The variations are not directly proportional and they are not equal in the area of each of the respective seven units. The southward movement is the least at Unit #1 increasing toward Unit #4, decreasing slightly at Unit #5 and approximately the same at Unit #6 as Unit #4, and considerably less at Unit #7 which is the east end of the present power house.

In the area of Unit #1 the southward movement is restrained by the keying of the west abutment into the rock and the concrete retaining wall in the tail race. At the east end there is no restraint but a large portion of the monolith adjacent to the future unit section is not exposed to intake water on both sides and a considerable portion is exposed to the atmosphere above the tail race water level at elevation +20. In these relatively dry surroundings the growth of the concrete is reduced as indicated by laboratory test results. In the area near Units 4, 5 and 6, the concrete is exposed over large areas to the intake waters, furthermore, the leakage around the intakes and into the inspection tunnel developed first in the area of Unit #5 indicating a gradual saturation of the concrete in the area.

The east and west movements are small due probably to the restriction by the rock on the west bank and the dam on the east end of the power house.

The difference in movement is confirmed by visible cracks at elevations +46 and++60 with the largest crack, open about three-quarters of an inch, located at elevation +60 just south of the "B" Line or at the junction of the circular walkway around Unit #4 with the main floor system. A second large crack open approximately five-eighths of an inch, occurs near Unit #6 at the connection of the floor and the down-river wall at elevation +46.

The maximum southward movement recorded at elevation +46 from 1944 to 1953 is approximately three-quarters of an inch at Unit #4 and #6. The movement at Unit #1 in the same period of time is three-eighths of an inch and at Unit #7 is one-half inch.

The east and west movement of practically all the points have varied back and forth, sometimes showing an easterly movement and sometimes a westerly movement with the net movements being easterly and not over one-quarter of an inch. The largest vertical movement is one-quarter of an inch and these are rather uniformly upward.

The measurements on the generator supporting frame have not indicated any appreciable change in the plane of the supports and up until this time there has been no evidence of the concrete movement affecting the vertical alignment of the units.

During the first few years, readings were taken over the survey points each winter and summer without too careful control as to their exact timing. Studies of the results of these early surveys indicated a need for closer scheduling in order to reduce to a minimum the variables in the problem. Examination also indicated that surveys at eighteen month rather than six month intervals would provide sufficient data to accurately gauge and plot the movements and continue to give the effect of the change of water temperature. Measurements have been taken at eighteen month intervals for the last two years.

The results of the surveys have been plotted in the form of bar charts to facilitate study and to determine where and when remedial measures will be necessary.

## Effect of Silting

The total movement of the structural concrete of the power house is considered to be the result of two separate actions, the major one being, of course, the growth of the concrete and the other we believe to be the effect of silting in the cracks that occur in the concrete due to temperature changes. A considerable increase in leakage in the lower part of the power house is evidenced each November or early December, reaching a maximum of 3 to 4 times the normal summer leakage. This is undoubtedly due to the contraction of the

concrete caused by the drop in temperature of the water, the average difference in temperature between summer and winter being approximately 50°F. After a storm or other disturbance of the pond, the water carries considerable fine silt and as this flows through the several cracks some of it is retained and the leakage reduces very rapidly before the first of the year. During the summer when the concrete expands due to the rise in the water temperature, the silt which was retained in the cracks is compressed and much of it remains permanently in the crack. The actual thickness of this compressed silt has not been and cannot be measured by any means at out disposal and its effect cannot be evaluated. It is possible that it is rather insignificant because the east and west movements are relatively small as was noted in results of the surveys. Also, the leakage in the butterfly valve areas has not decreased over the years except after the previously noted grouting.

## Conclusion

While this paper should be considered an interum report, certain conclusions have been drawn and future policy determined.

The laboratory tests indicate there are two unusual characteristics of the concrete which may point to the cause of the movement which has developed in the structure. These characteristics are:

(1) The continuing expansion of the concrete cores during exposure to repeated cycles of temperature change.

(2) The relatively high expansion of some of the laboratory specimens made either with a high-alkali cement or with this cement plus 1% sodium hydroxide.

Tests for alkali-aggregate reaction have not produced extremely high expansions during the 18 month period of test, but some of the expansions are higher than would be expected with normal aggregate and the trend of some of the curves suggests that there may be some reactivity. At any rate it is still too early to discount the possibility of alkali-aggregate reaction since such reactions often require a period of years to develop, and since some slight evidence of such reaction was found in the examinations of the original concrete cores.

The expansion of the cores subjected to repeated cycles of temperature change (40 to 90°F) is considerably greater than that obtained with the laboratory made specimens. It may be, therefore, that a similar effect caused by annual temperature variations in the structure is a contributing factor in the movements obtained in the concrete. The power plant is subjected to only one complete cycle of temperature change a year, and thus has received only 25 cycles to date. It is difficult to believe that this alone could be the cause of all the movement of the concrete which has occurred in the structure. However, when this effect is added to the normal expansion of the concrete exposed to moisture and possibly to some expansion due to slight alkali-aggregate reaction, the expansions experienced can be accounted for.

It has been pointed out that the concrete was high in water content and that all of the cement had been hydrated, but there is no record of the alkali content of the cements used.

There is nothing in the results to suggest how long the movement of the concrete will continue. However an analysis of several laboratory tests on three substructure cores immersed in water and alternately heated and cooled so that they received a cyclic change for 90°F to 40°F does give some encouraging indications of a decrease in the rate of growth as shown in the following table:

| Cycles | For 90°, the % Change per Cycle | For 40°, the % Change per Cycle |
|---|---|---|
| 0 to 10 | 0.0039 | 0.0016 |
| 10 to 20 | 0.0010 | 0.0008 |
| 20 to 30 | 0.0005 | 0.0005 |
| 30 to 40* | 0.0007 | 0.0010 |
| 40 to 50 | 0.0005 | 0.0004 |
| 50 to 100 | 0.0004 | 0.0003 |

Similar tests on superstructure cores

| Cycles | For 90°, the % Change per Cycle | For 40°, the % Change per Cycle |
|---|---|---|
| 0 to 10 | 0.0032 | 0.0012 |
| 10 to 20 | 0.0007 | 0.0008 |
| 20 to 30 | 0.0005 | 0.0007 |
| 30 to 40* | 0.0008 | 0.0007 |
| 40 to 50 | 0.0004 | 0.0005 |
| 50 to 100 | 0.0003 | 0.0004 |

* Laboratory equipment not available for full temperature cycle during this period.

It is interesting to note, if the movement of one-half inch recorded by the plumb at Unit #4 up to 1943 and the maximum survey reading by 1953 of three-quarters of an inch are considered cumulative, the total measured movement then is one and a quarter inches; in comparison, by taking the width of the plant from the centerline of the key in the rock under the head works to the downriver face of the structure, which distance is one hundred and fifty feet and applying the laboratory results on cores from that part of the structure, the calculated results would indicate a movement of 0.105 feet or one and a quarter inches, also.

There is no indication of overall structural weakness in the powerhouse and there is no concern except to insure the integrity of operation of the equipment.

## Future Policy and Plans

Measurements of the survey system are scheduled to be continued at 18 month intervals (in January and July) until an indication of negligible movement is recorded, as none of the tests or readings can forecast that date.

In general, there is no plan to replace any concrete in the near future. If operating conditions indicate the necessity for local relief, immediate steps will be taken to accomplish such relief.

The cracks at the downriver wall at Elevation +48 definitely show a separation between the floor and the wall, this naturally is decreasing the bearing of the steel floor beams on the wall. As the bearing distance was less than normal due to the column arrangement in the wall, the condition is being watched very carefully and if it becomes critical, additional bearing surface will be provided extending from the mass concrete at Elevation +35 to the under side of the floor beams.

As additional data is collected, or major corrective measures become necessary, further reports will be made available to interested members.

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